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TITLE THE APPLICATION OF DOE-2 IN THE PREDESIGN PHASE OF COMMERCIAL-BUILDING DESIGN

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THE APPLICATION OF DOE-2 IN THE PREDESIGN PHASE OF COMMERCIAL-BUILDING DESIGN*

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ABSTRACT

This paper presents the results of a study in applying a high-level, computer-dynamic tool, DOE-2, to the predesign process for a standard test office building. This study was part of a larger study funded by DOE wherein five analysis tools, ranging from manual to computer-dynamic methods, were used to provide predesign energy information. The purpose was to test whether computer-dynamic tools, such as DOE-2 and BLAST, can readily provide the necessary predesign information in a usable visual format and without excessive cost.

1. INTRODUCTION

Buildings in the commercial sector of the United States accounted for nearly 14% of the total primary energy used by the United States in 1977.[1] Forecasts[1] indicate that new commercial space will be constructed at such a rapid rate during the next 20 years that nearly 53% of the commercial building stock standing in the year 2000 will have been built after 1980. Thus, the potential of saving significant energy in new commercial buildings constructed throughout the rest of the century portends a considerable opportunity.

Unfortunately, there is substantial evidence of failure in the professional design community to design buildings that conserve energy at cost-effective levels. A major problem lies in the process by which commercial buildings are designed. Traditionally, the prime design determinants of form, function, cost, and time have not been constrained by energy concerns. Energy must be considered as a design determinant in the earliest stages of the design if the potential of 60% to 65% energy savings noted in a few recent design experiences are to be realized.

Another problem limiting the successful implementation of cost-effective energy conservation measures is the unavailability of design tools that quickly, inexpensively, and effectively communicate the energy problems and potentials of large, complex buildings. Although many energy analysis techniques, such as modified degree-day and bin procedures and graphical methods, have been developed for commercial buildings,[2] most are suited to smaller structures with thermal loads that depend largely on the difference between indoor and outdoor dry-bulb temperature. Other methods, such as comprehensive building energy analysis computer programs, are more appropriate for the diverse architectural, energy, and operational characteristics of large commercial buildings. DOE-2 is an example of such a computer program.

It is widely held that high-level computer-dynamic (hour-by-hour) computer programs such as DOE-2 and BLAST cannot readily provide needed predesign information in a usable visual format and without excessive cost. To test this conjecture, a study was funded by DOE wherein five analysis tools, ranging from manual methods to computer-dynamic methods, were used to provide predesign information for a standard test building. This paper presents the results and experiences of the authors in using DOE-2, one of the five tools studied.

2. APPROACH

2.1 Development of the Standard Test Building

The first issue to be resolved was the development of a minimum specification of input that would test the suitability of each method in analyzing a moderately complex commercial building. An additional issue was that the input be chosen to characterize the energy diversity in actual

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buildings. A single-story office building in Pittsburgh, Pennsylvania was selected with zoning as shown in Fig. 1. The specification of input is presented in Table I.

Although DOE-2 has been criticized as requiring a large amount of input data, the information provided in Table I was sufficient to run the program and to produce the required output. With the exception of the assumptions listed in Table I, all of the input data are directly derivable from either the building architectural program or site conditions. The program was allowed to default all other input A listing of the input is found in Ref. 3.

2.2 Output Desired in the Predesign Phase

The primary focus of the study was the development of a sufficient set of output that was supportive of the predesign process. Decisions made during the predesign phase are critical to the development of design concepts that are acceptable in terms of architecture, energy technology, and economics. Furthermore, mistakes made in this process can be avoided by providing the designer with sufficient information in a visual format that would educate his/her intuition in characterizing energy use. The questions most likely to be asked in the predesign phase are

- What is the major energy problem of the the building?
- What factors contribute to this problem?
- Given these contributing factors, what design strategies are indicated for an energy-efficient design?
- What are the operating costs of the building?

The project participants found that these questions could be answered by providing information to the designer in the format shown in Figs. 2-5.

3. RESULTS

The annual energy consumed and the costs of the fuel consumed by the primary system equipment in the sample test building are shown in Fig. 2. The loads shown are the thermal loads met at the HVAC system heating and cooling coils or domestic hot water loads that are imposed on the domestic hot water boiler. In addition, the electricity supplied to office equipment constitutes the electric load shown for miscellaneous equipment. Energy loads, consumption and cost are broken down by end use. Note that heating is the major energy problem for this sample building.

Figure 3 presents energy demand and associated demand cost information, which, when coupled with the information shown in Fig. 2, defines the operating cost of the building. Annual demand is calculated by averaging the monthly peak building electric loads that occur during the year, whereas, the peak load is the largest coincident

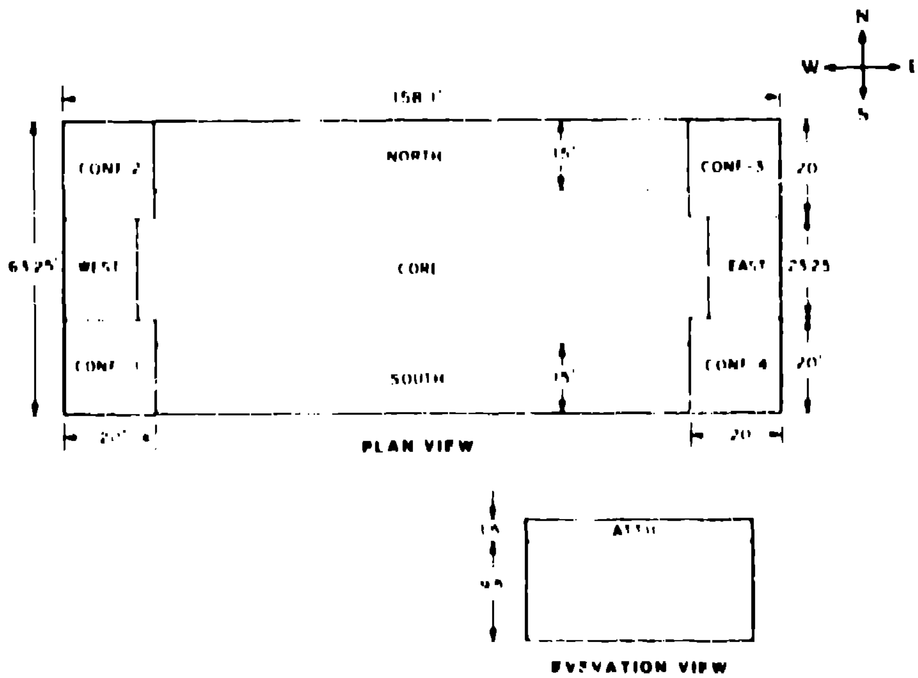

Fig. 1. Zoning arrangement for the sample test problem.

TABLE I

SAMPLE PROBLEM INPUT

- Location: Pittsburgh, Pennsylvania; Test Reference Year (TRY) hour-by-hour weather data was used by the comprehensive energy analysis computer programs.
- Site: Flat and not shaded
- Building Type: One-story office building
- Building Area: 10,000 ft^2
- Building Orientation: East-west axis
- Occupancy:

	Office Area	Conference Area
	200 ft^2/person	30 ft^2/person
	8 a.m. - 5 p.m.	10 a.m. - 3 p.m.
	Monday-Friday	Wednesday

Sensible heat gain = 250 Btu/h-person
Latent heat gain = 200 Btu/h-person

- Ventilation: 7-1/2 CFM in occupied office area
  15 CFM in occupied conference area
- Infiltration: 1/4 air-change/h in occupied perimeter area
  No infiltration in the core area
- Lighting: 1.0 watt/ft^2 occupied
  0.1 watt/ft^2 unoccupied
- Equipment: 0.1 watt/ft^2 in occupied office area
- Interior Environment:

	Occupied	Unoccupied
Heating	68°F	55°F
Cooling	78°F	90°F

- Hot Water: 1 gallon/day-person
  50°F inlet and 120°F outlet
- Fuel Rates: Oil heat at \$1.25/gallon
  Electricity at 4¢/kWh and \$2.85/kW/month demand
- Assumptions:

Building configuration: See Fig. 1.
Mass: 4-in concrete slab floor, fully carpeted
4-in steel stud framing with gypsum board
Hung ceiling with built-up roof
Fenestration: Window area 50% of non-attic walls
- double pane glass
- shading coefficient - 0.58
Skylight area 5% of roof area
- U = 0.70 Btu/ft^2-h-°F
shading coefficient - 0.82
Walls: R-14; solar absorptance - 0.5
Roof: R-15; solar absorptance - 0.7
Floor: Adiabatic; solar absorptance - 0.5
Hung Ceiling: R-2.5; solar absorptance - 0.5
Interior Walls: Solar absortpance - 0.5
HVAC System: Central variable-air-volume cooling
Perimeter baseboard heating
Static fan pressure - 2.5 in. H_2O
Fan-motor efficiency - 0.62
Cold deck temperature - 55°F
Variable speed driven fan
Diffuser turn-down ratio - 0.2
Enthalpy economizer
Primary System: Heating efficiency - 60%
Cooling COP - 3.0

building electric load occuring during the year. The costs are the annual utility charges for electric demand.

Figure 4 provides a seasonal summary of the energy problem for the whole building. It relates the cost of each energy end use, plus energy demand, to the total operating cost of the building. W, S, S, and F represent winter, spring, summer, and fall seasons, respectively; O and U specify the building as being occupied or unoccupied. Specific causes of the energy problem are shown. The symbols ●, ◐, and ○ rank the causes of the building energy problem in descending order of significance. For example, glazing conduction, as indicated by

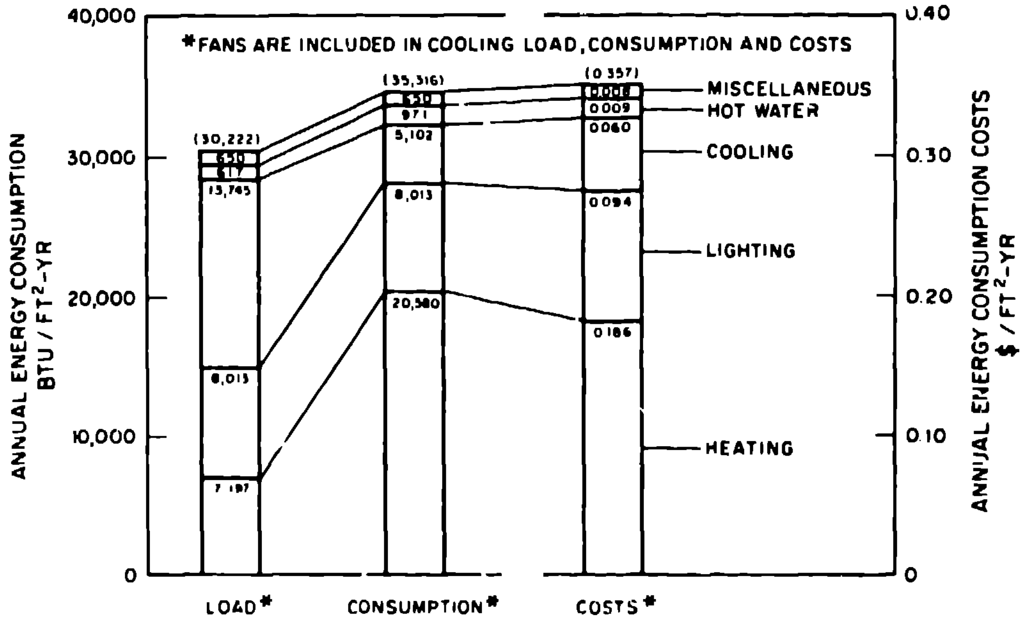

Fig. 2. Annual energy consumption costs.

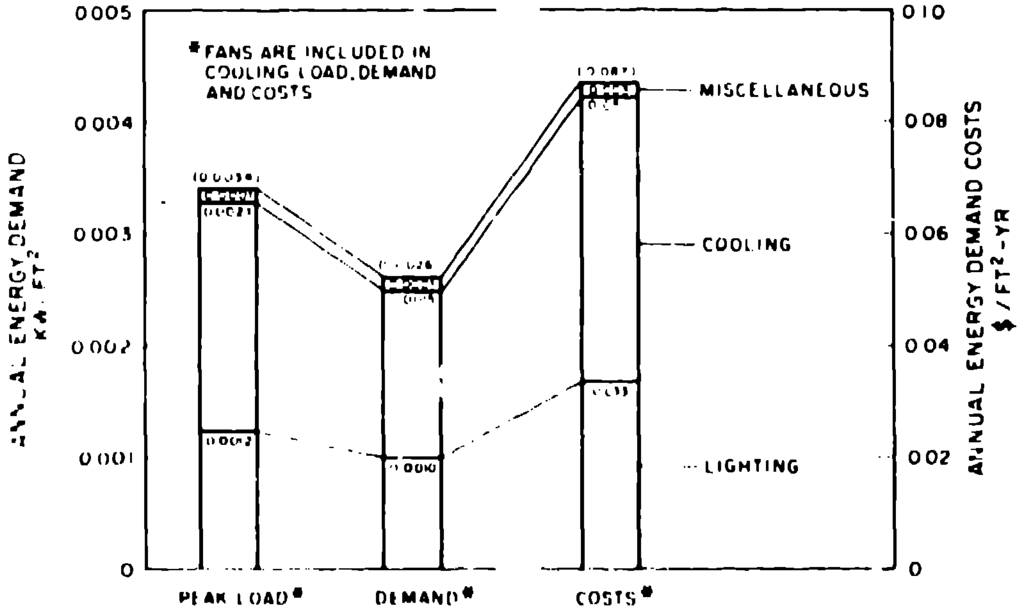

Fig. 3. Annual energy demand costs.

the symbol ●, contributes more to the heating problem than any of the other components of the load. This is followed to a lesser degree by roofs and infiltration. Similarly, 1 and 2 rank the building orientation as specific causes of the energy problem in descending order of significance.

Finally, Fig. [illegible] shows the seasonal time phasing of the thermal loads. These results suggest that design strategies addressing the heating load should eliminate an early morning startup peak and should minimize summer cooling loads in the mid-afternoon. The typical days for the seasons were selected from the weather data presented in Ref. 4 for the months of January, April, July, and October.

These figures support the transfer of vital information to the designer in a form that can be quickly understood. Note that DOE 2

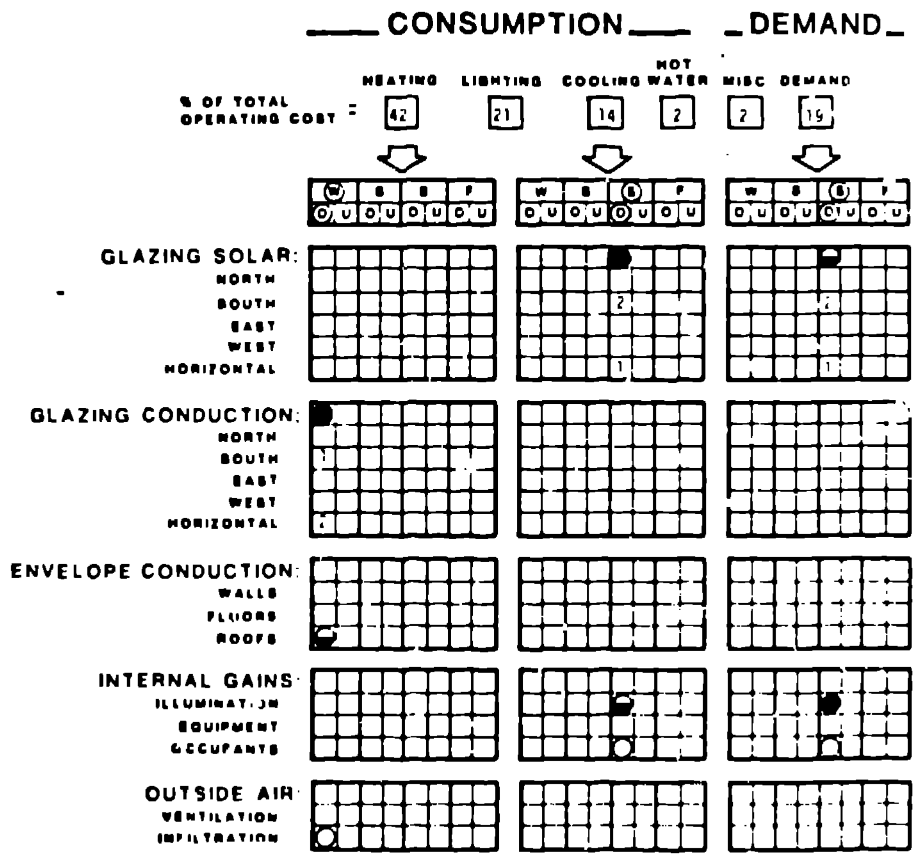

Fig. 4. Energy problem matrix.

can generate all of the required data. A detailed explanation of how each of these figures is developed using the DOE-2 standard and hourly output reports is provided in Ref. 3.

4. ASSESSMENT OF THE APPLICABILITY OF DOE-2.1 TO THE PREDESIGN PROCESS

Although the use of DOE-2 can produce all of the information presented in Figs. 2-5, it cannot automatically produce the output in a graphic format. Furthermore, all the information is not available from a single DOE-2 run. For example, to calculate the loads shown in Fig. 2, three computer runs had to be made. An initial run was made (using system SUM) to determine the building thermal loads with the indoor air temperature control strategy described in the sample problem input. (The LOADS program output was not used because the building energy fluxes are calculated at a constant temperature in the DOE-2 LOADS program.) However, this run does not simulate mechanical ventilation, so two additional runs, one with and one without ventilation, were made using the system data specified for the sample problem input. The ventilation load was then added to the thermal loads calculated in the SUM run to produce the total thermal loads presented.

Another problem occurs in the calculation of the energy demand shown in Fig. 3. The standard DOE-2 output reports do not break down the electric demand for each piece of equipment, such as lights, chillers, fans, and pumps on a monthly basis, so it is difficult to allocate demand charges to the lighting, cooling, and miscellaneous categories shown in Fig. 3. Reference 3 provides a methodology for determining this breakdown, but the method is awkward and relies on assumptions that do not apply to every type of mechanical system.

The calculation technique of the DOE-2 program creates an additional problem. Figure 4 is used to summarize information about the causes of energy use in the building. But what is cause (in the building energy use sense)? In this context, cause is a component of the building energy flux that encourages energy consumption. The component energy fluxes shown in Fig. 4 were calculated in the LOADS program assuming a constant space temperature. Because these fluxes do not represent the component energy

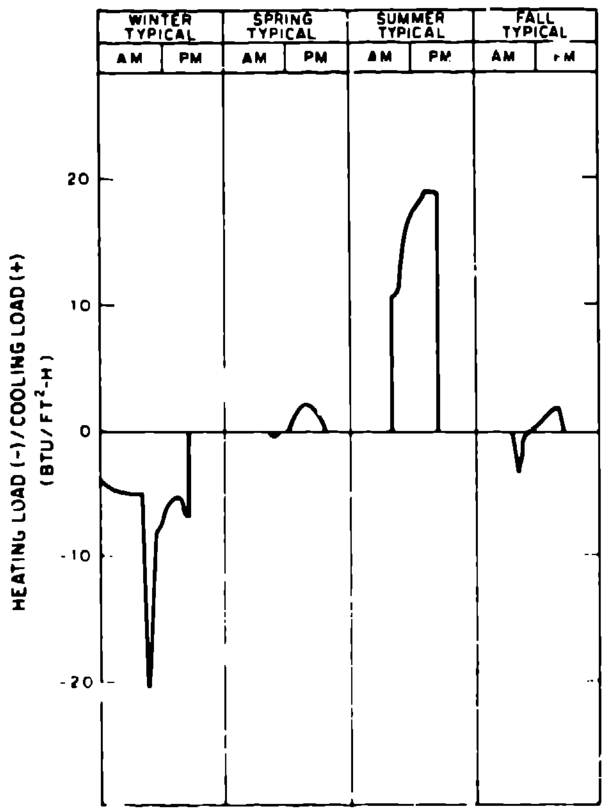

Fig. 5. Building loads for typical days each season.

fluxes that occur in a real building with varying space temperature, they do not necessarily induce energy consumption. Even if precise component energy fluxes were calculated, energy consumption would not necessarily be induced in proportion to these fluxes. This is particularly true when space temperatures float within the deadband of the thermostat. In other words, energy consumption in commercial buildings is rarely directly proportional to building load. Consequently, the results presented in Fig. 4 are qualitative judgements of cause supported by an imperfect quantitative analysis.

A total of five DOE-2 computer runs, including two runs simulating typical-day input for the four seasons shown in Fig. 5, were required to develop the output supporting the predesign process in this study. Because each of these runs is built on a common input data base, significant savings in the development of input data were realized. However, the time expended (about one man-week) to use DOE-2 in the predesign analysis of a building cannot be justified unless potential solutions to the design problem are also desired. Once a base building is defined for a predesign analysis, it is a simple matter to perform multiple parametrics using DOE-2 to identify potential design solutions.

5 CONCLUSIONS

The results of the predesign analysis study reported here dispel the myth that DOE-2 requires a large amount of detailed input and, therefore, does not lend itself to the predesign process. Furthermore, DOE-2 is shown to be capable of generating the data required to answer the fundamental questions of the predesign energy analysis process. However, multiple runs were required and the graphical output had to be developed by hand.

A major effort to reconstruct the DOE-2 program to calculate building thermal loads with variable interior air temperature has been proposed. However, this capability would do little to improve the program's ability to identify the causes of the energy problem. The results of this study have shown that sufficient quantitative capability is currently available in the program to make reasonable judgements of cause.

The use of DOE-2 in the predesign process involves about 5 days of the professional services of an energy analyst skilled in the use of the program. The commitment of this effort in the predesign phase of a commercial building design seems a small price to pay for identifying a cost-effective energy strategy. However, the client must value the potential benefits and be prepared to pay the fee.

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